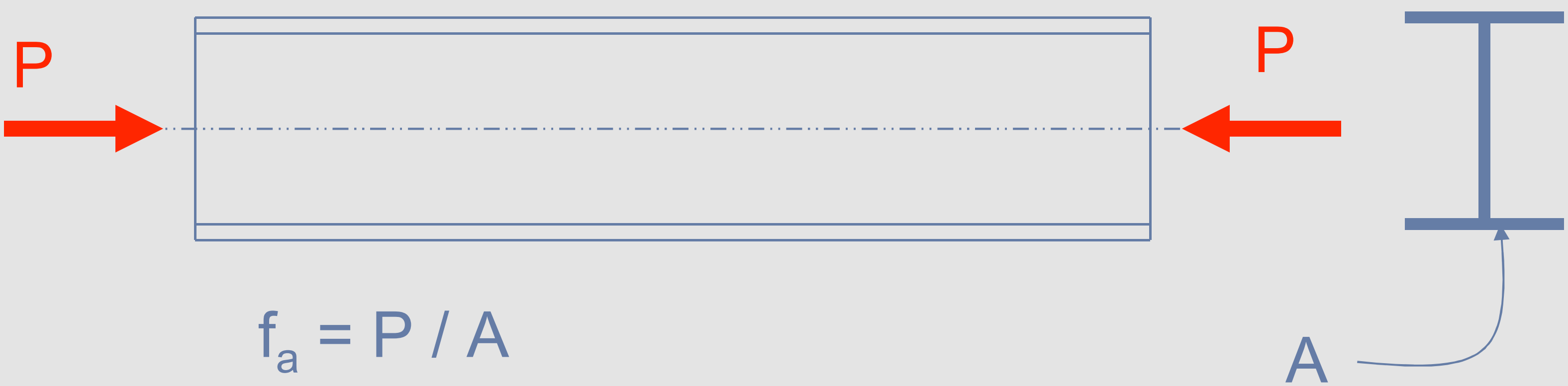
C & EE 141

Compression Members

Definition

- Elements which are subjected only to axial compressive forces are defined as **columns.**
- Loads are applied along the longitudinal centroidal axis with no eccentricity.



$f_a = P / A$

Idealized State of Concentric Loading

- The ideal state of concentric loading is never achieved. Some eccentricities always exist.
  - Members are not perfectly straight
  - Connections cause eccentricities
  - Internal stresses cause uneven stress distribution
- "Φ" factor accounts for inherent eccentricities.
- For significant eccentricities, we design a beam-column, which will be addressed in future lectures.

Common Compression Members

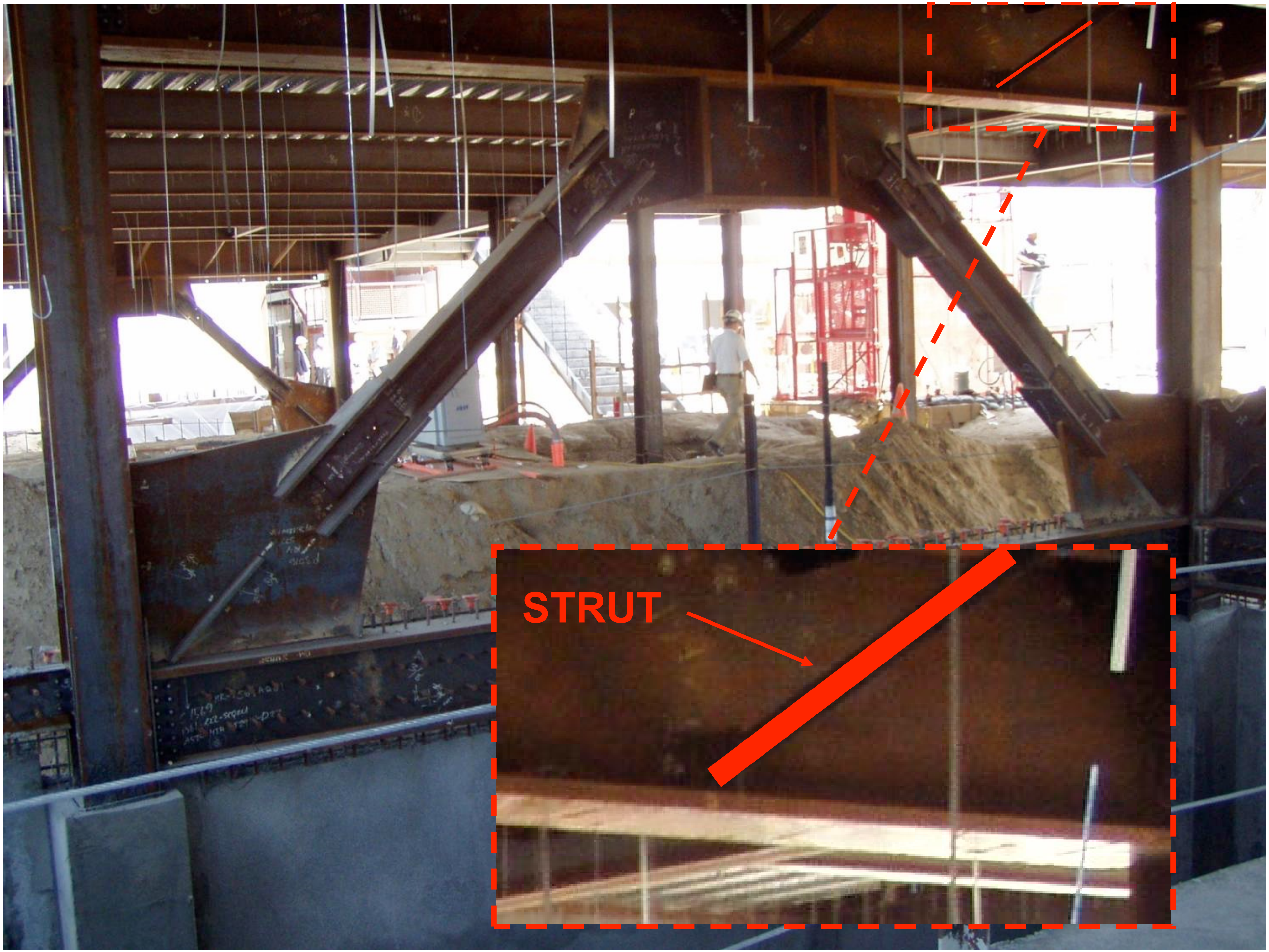
- Columns
- Braces
- Truss members
- Struts or Kickers

COLUMN

BRACES

Trusses

- Members in Compression
- Members in Tension

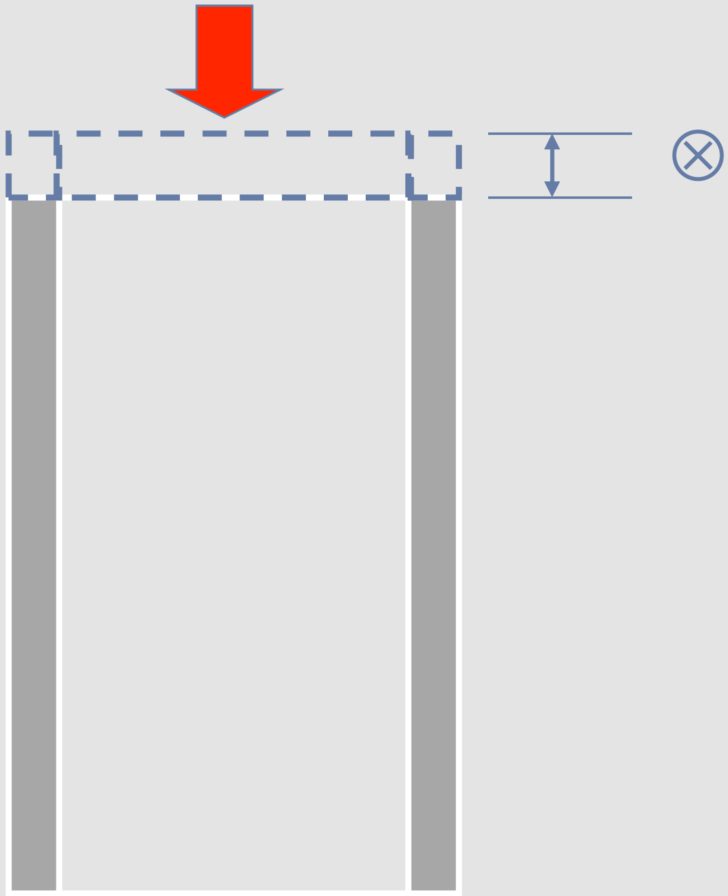

STRUT

Column Limit States

- Compression Yielding
  - Occurs only in very short or stout columns
- Global Buckling
  - Instability of the entire column
  - Strength is function of column length
- Local Buckling
  - Instability of a part of the column

Compression Yielding

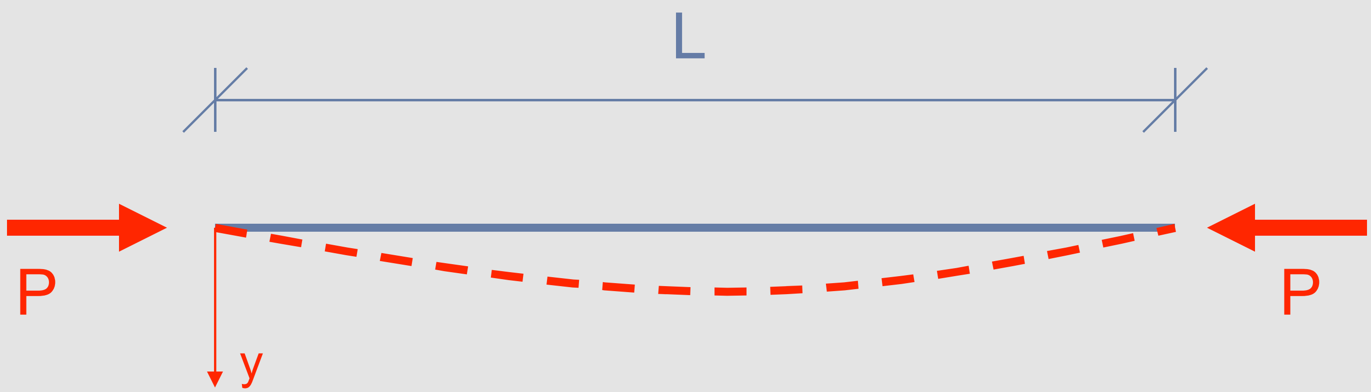
$$P_n = A_g F_y$$



Global Buckling

This type of buckling is elastic. When the load is removed, the member returns to its original shape

Column Theory



Fundamental Buckling Mode for a column in single curvature with pinned-end connections can be derived using differential equations. (Euler buckling—see Geschwindner Section 5.3).

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

Column Theory (Cont.)

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

Or in terms of average compressive stress:

$I = A_g r^2 \qquad r = \sqrt{I/A}$

$$F_{cr} = \frac{\pi^2 E}{\left(L/r\right)^2}$$

Critical buckling stress is a function of length, and radius of gyration (or, "slenderness ratio" L/r)

Elastic Buckling

- $$F_{cr} = \frac{\pi^2 E}{\left(\frac{L}{r}\right)^2}$$ (Euler Buckling)
- Problem: If L is very small, F could be infinite!
- But F_{max} must be F_y, the yield stress of the material (Compression Yielding).
- Another limit state, known as Inelastic Buckling, occurs which transitions from Elastic Buckling to Compression Yielding.

Inelastic Buckling

- What is Physically Occurring?
  - A combination of compression yielding and elastic buckling in different parts of the cross-section.
- Why?

Inelastic Buckling

- Residual stresses are present in W Shapes due to cooling. Like a pie, the edges cool faster than the inside. For a W shape, flange tips cool fast, and web-flange connections stay hot.

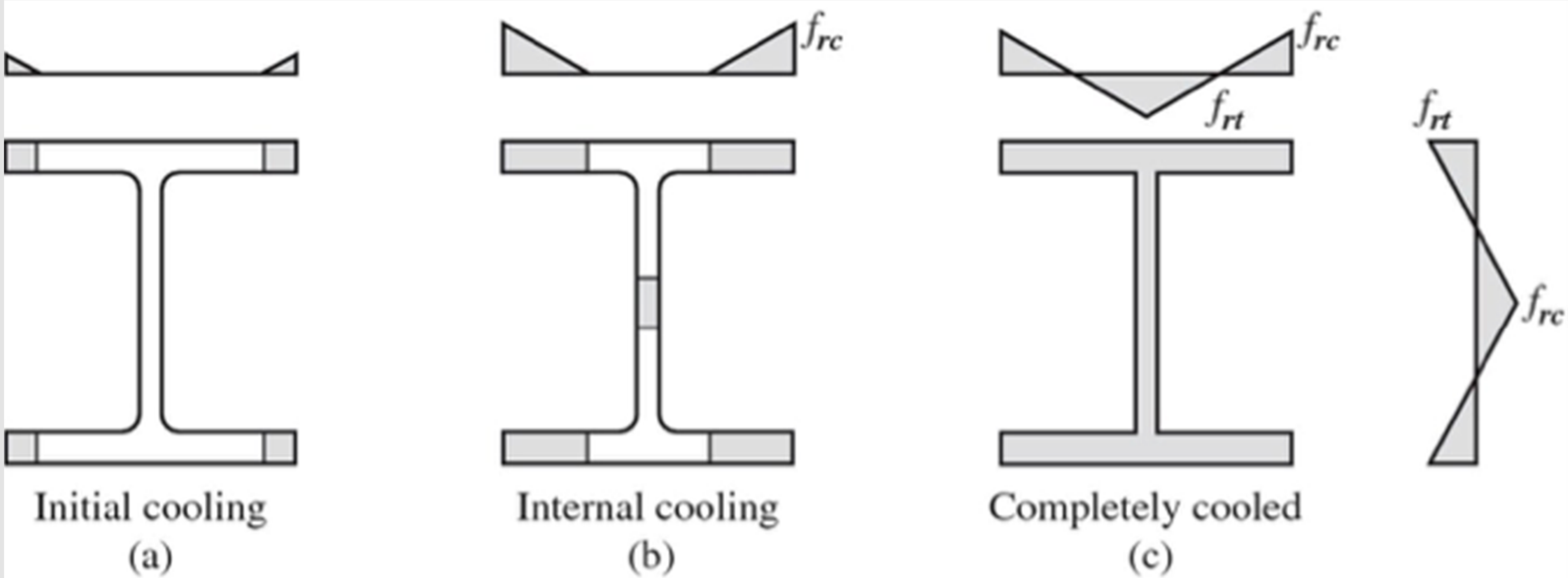


Figure 5.10

Inelastic Buckling

- This creates a "transition zone" between elastic and plastic behavior, between the proportional limit and the yield stress.

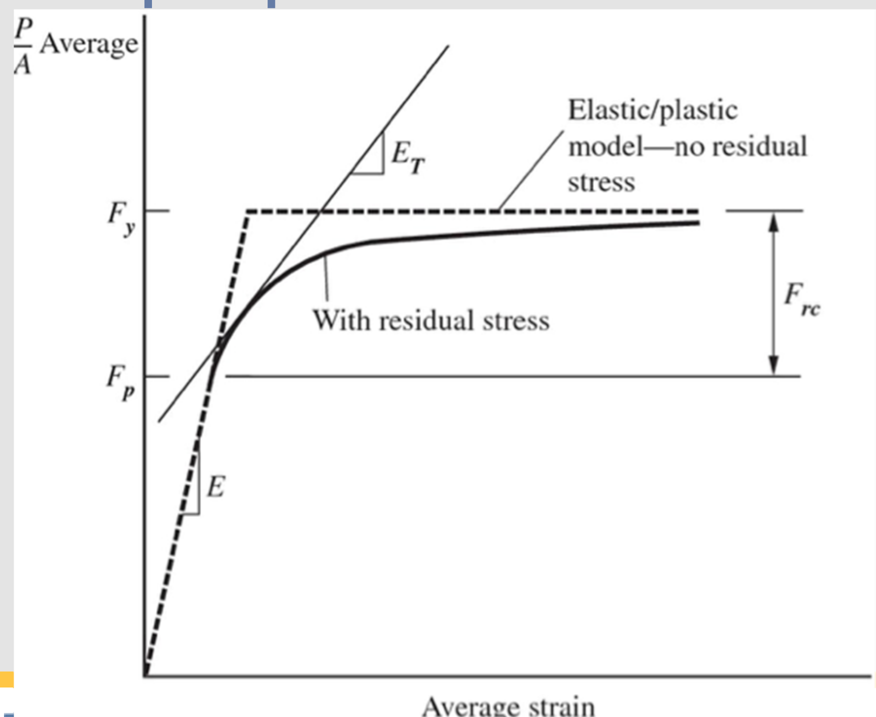
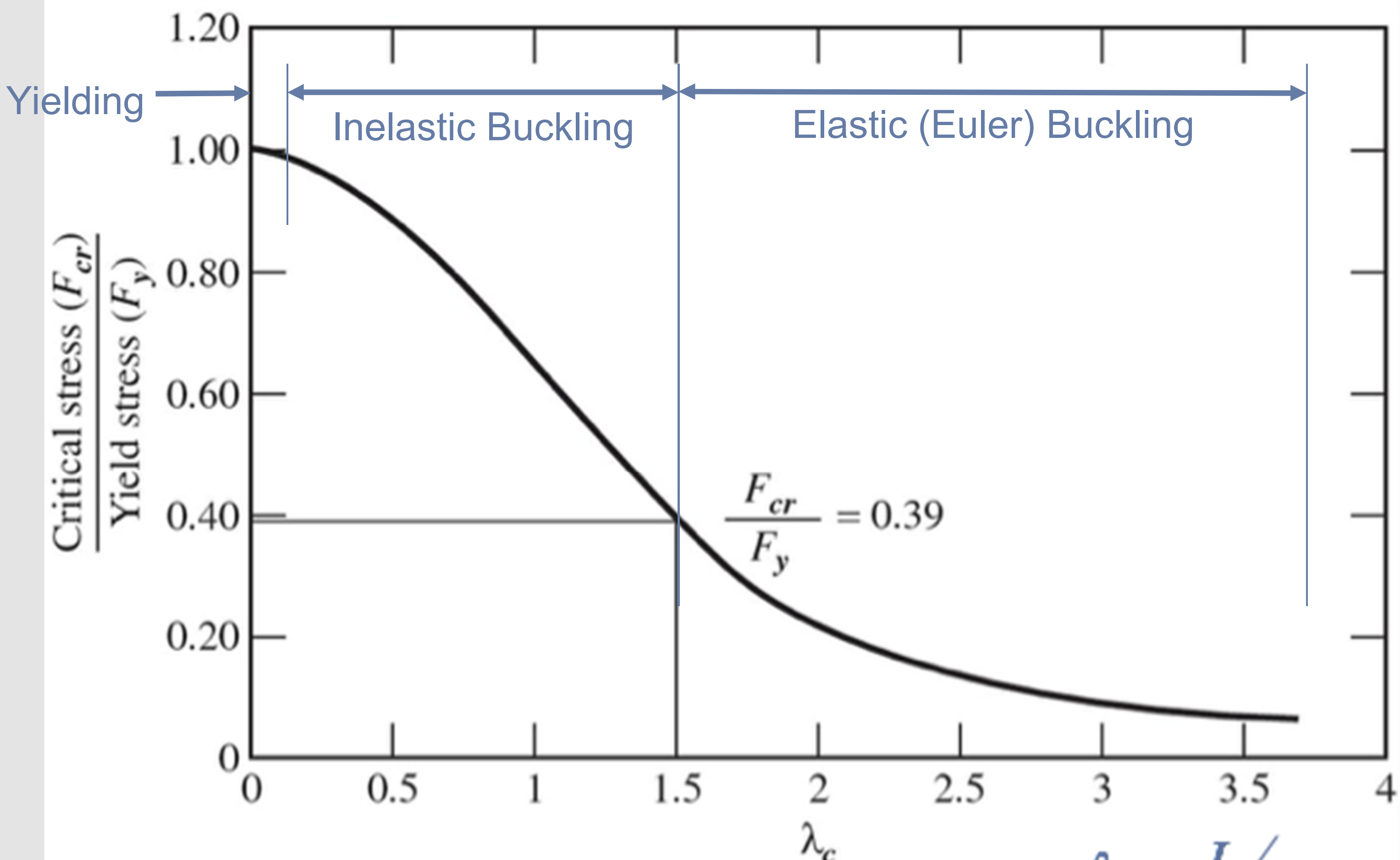


Figure 5.11

The equations are derived using a differential tangent modulus, E_t. (Engesser's Solution)

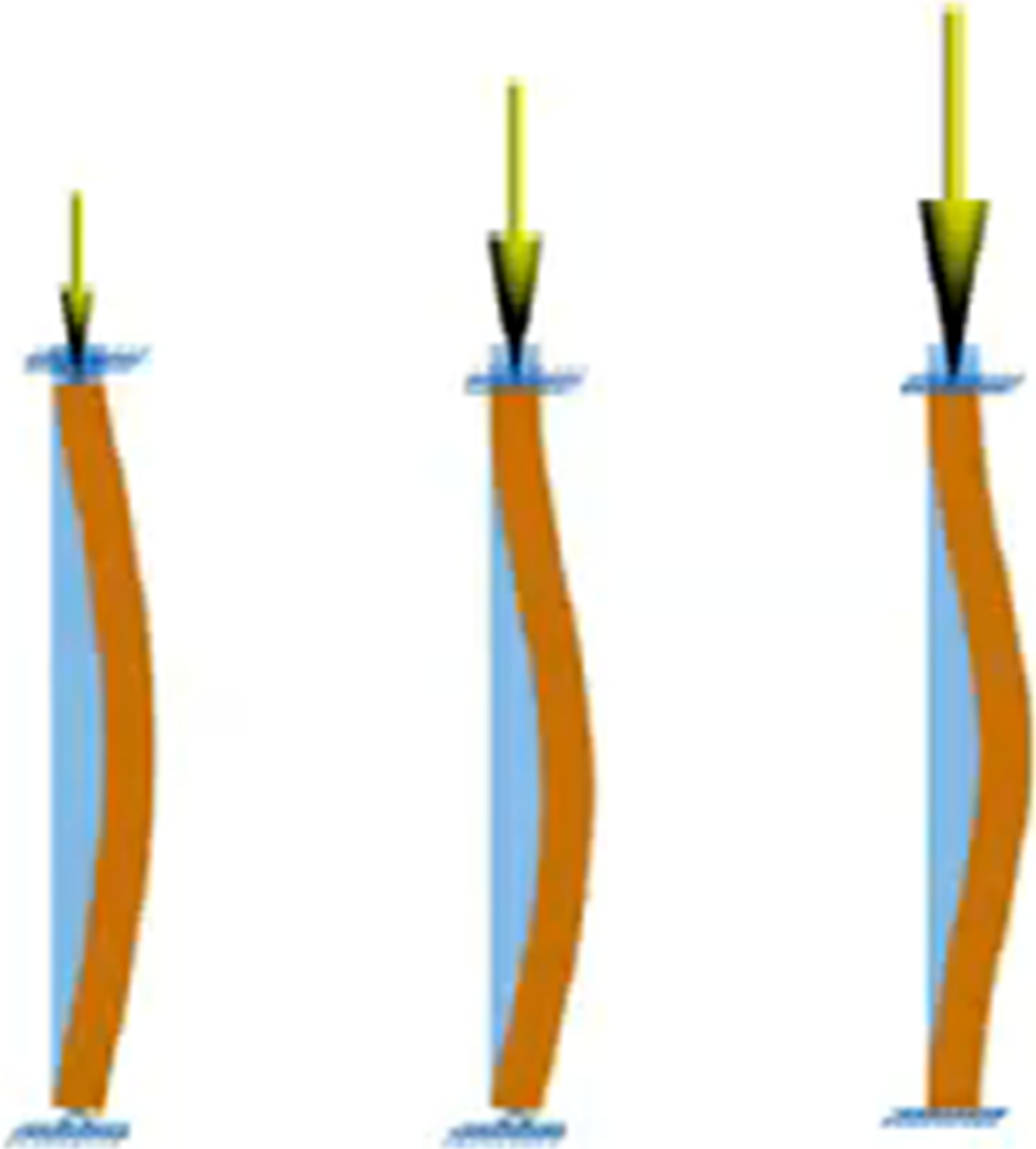
$$\mathbf{P_{cr} = \pi^2 E_t I / L^2}$$

Transitions in Column Behavior



Note: $\lambda_c \propto L/r$

Figure 5.15



Effective Length

- Differential equations can also be solved for other boundary conditions
- We use a concept known as **effective length, K** to account for other boundary conditions.
- Understanding K:
  - Ask the question: What would the length be to "mimic" 1^{st} order buckling in a pin-pin connection?

Effective Length, K

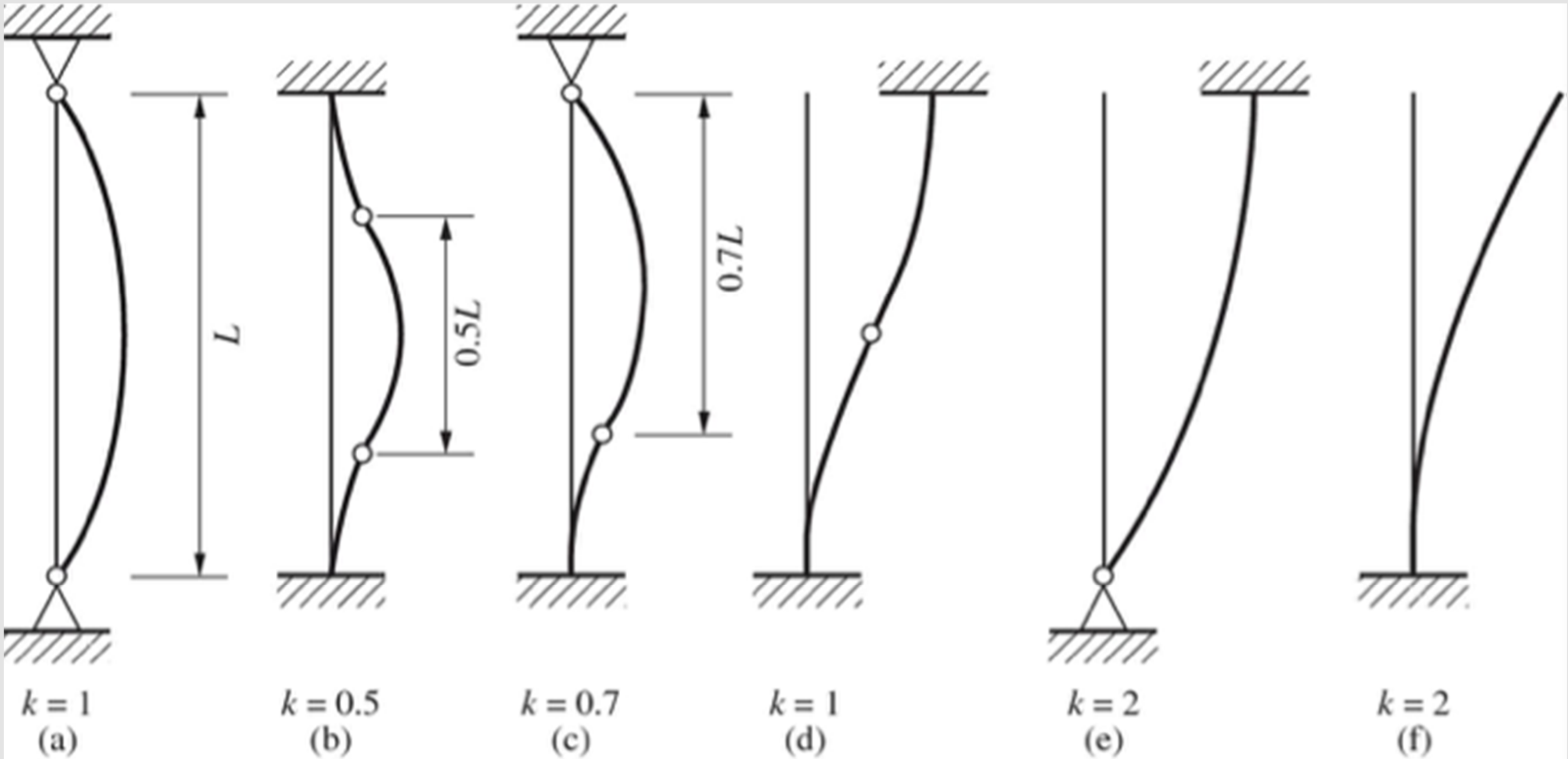
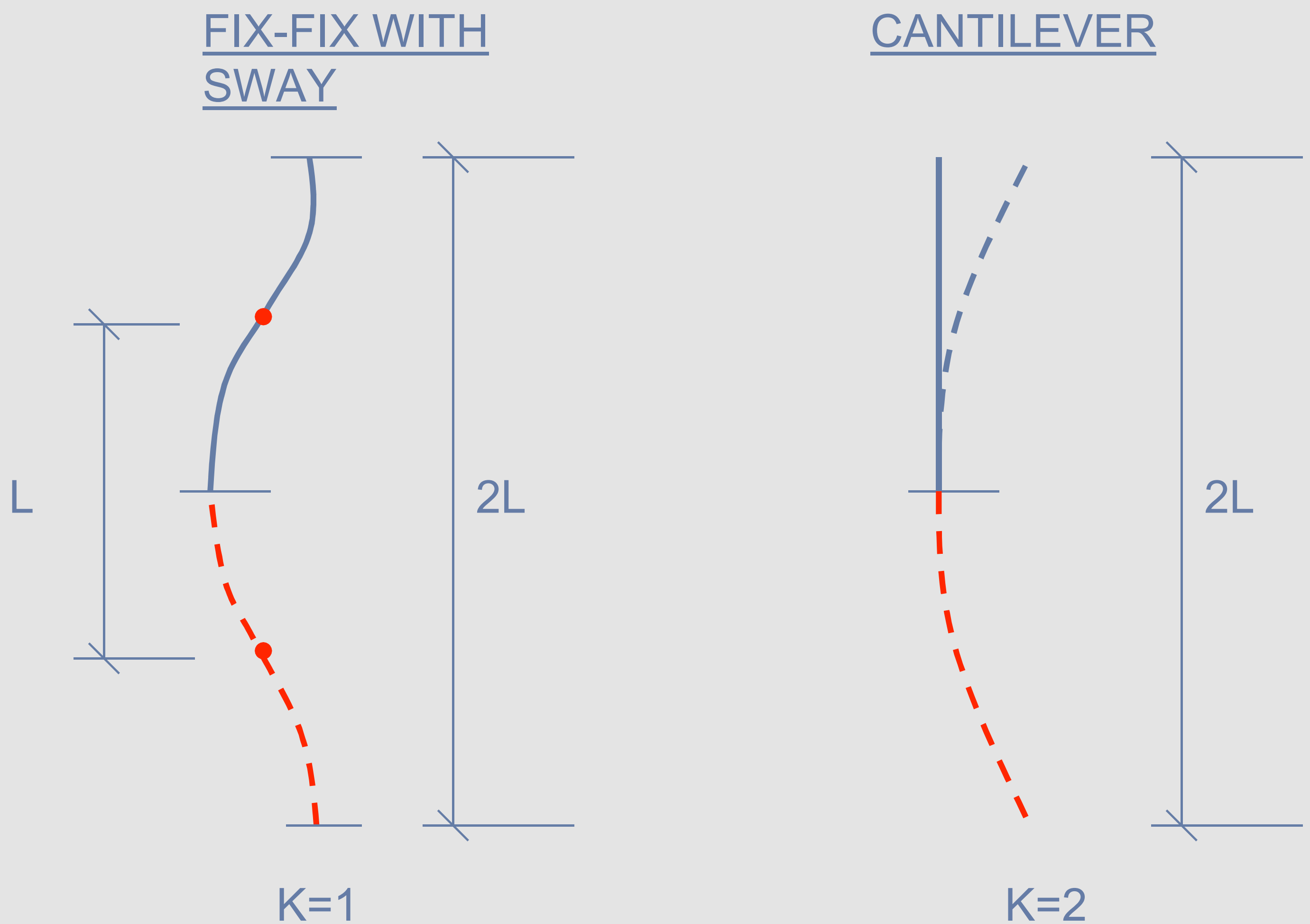


Figure 5.6

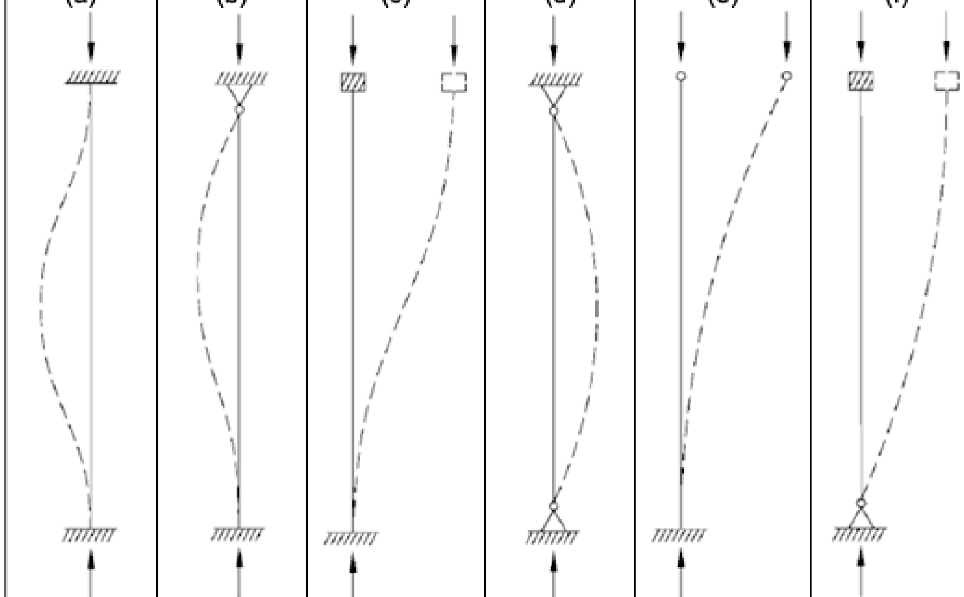
Effective Length, K



Effective Length, K

- Rotation fixed and translation fixed
- Rotation free and translation fixed
- Rotation fixed and translation free
- Rotation free and translation free

TABLE C-A-7.1
Approximate Values of Effective Length Factor, *K*

	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line						
Theoretical *K* value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.1	2.0

Axial Capacity

- $P_u \le \phi_c P_n$
  - $\phi_c = 0.90$ (Section E1)
  - $P_n = F_{cr} A_g$ (nominal compressive strength)
  - F_{cr} (critical stress, Section E3)
    - $F_{cr} = [0.658^{F_y/F_e}]F_y$ for $KL/r \le 4.71\sqrt{E/F_y}$ **INELASTIC BUCKLING**
    - $F_{cr} = 0.877F_e$ for $KL/r > 4.71\sqrt{E/F_y}$ **ELASTIC BUCKLING**
    - $F_{cr} \le F_y$ **YIELDING**
    - Use largest value of KL/r for either x-x or y-y axis

E3. FLEXURAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

This section applies to nonslender element compression members as defined in Section B4.1 for elements in uniform compression.

> **User Note:** When the torsional *unbraced length* is larger than the lateral unbraced length, Section E4 may control the design of wide flange and similarly shaped *columns*.

The *nominal compressive strength*, P_n, shall be determined based on the *limit state* of *flexural buckling*.

$$P_n = F_{cr} A_g \tag{E3-1}$$

The *critical stress*, F_{cr}, is determined as follows:

(a) When $\dfrac{KL}{r} \le 4.71\sqrt{\dfrac{E}{F_y}}$ (or $\dfrac{F_y}{F_e} \le 2.25$)

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y \tag{E3-2}$$

(b) When $\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

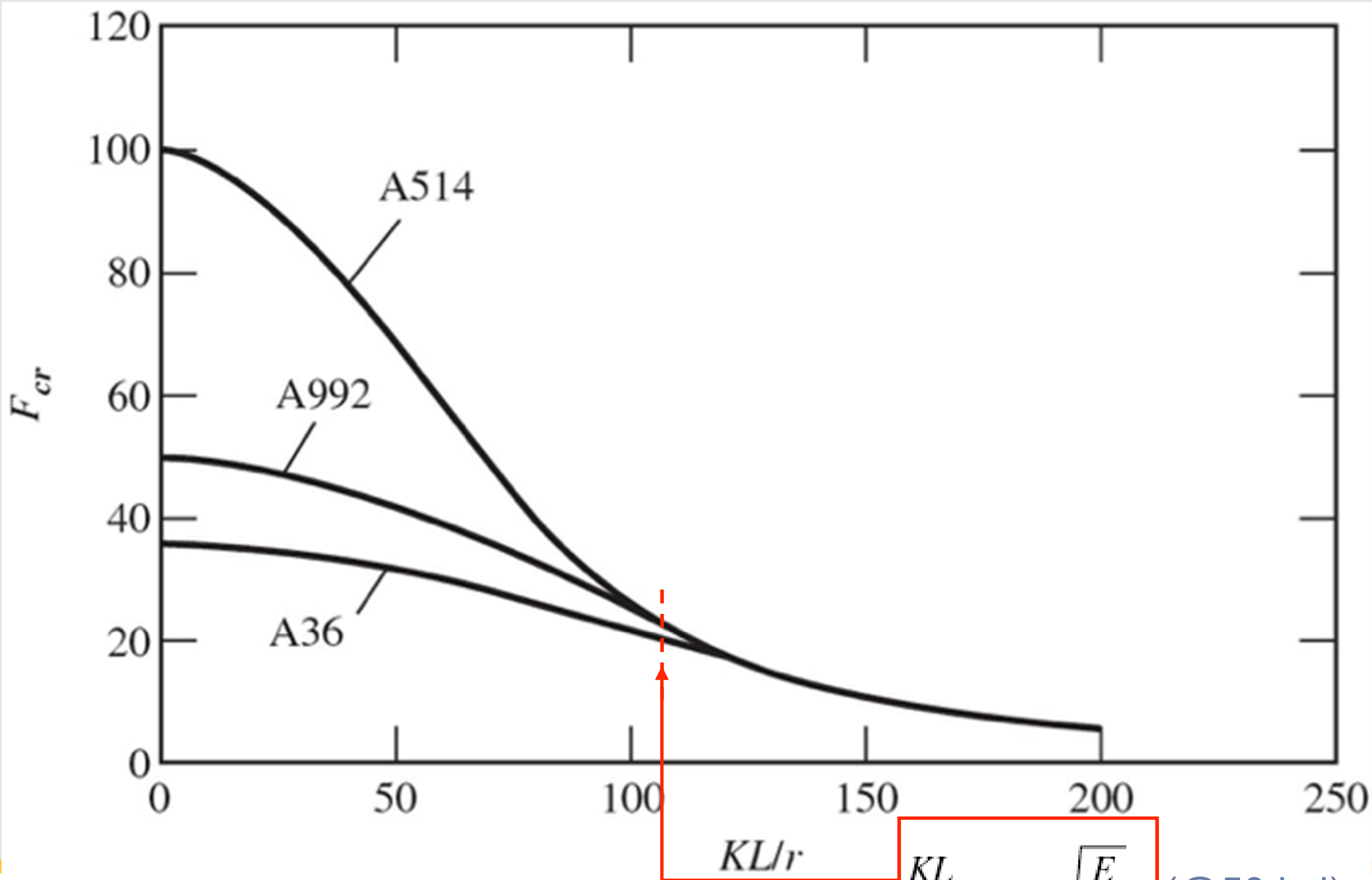
$$F_{cr} = 0.877F_e \qquad \text{(E3-3)}$$

where

F_e = elastic *buckling* stress determined according to Equation E3-4, as specified in Appendix 7, Section 7.2.3(b), or through an elastic buckling analysis, as applicable, ksi (MPa)

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \qquad \text{(E3-4)}$$

AISC Provisions



$$\frac{KL}{r} \le 4.71\sqrt{\frac{E}{F_y}}$$ (@50 ksi)

Figure 5.14

Maximum Slenderness Ratio

E2. EFFECTIVE LENGTH

The *effective length factor*, K, for calculation of member slenderness, KL/r, shall be determined in accordance with Chapter C or Appendix 7,

where

L = laterally *unbraced length* of the member, in. (mm)

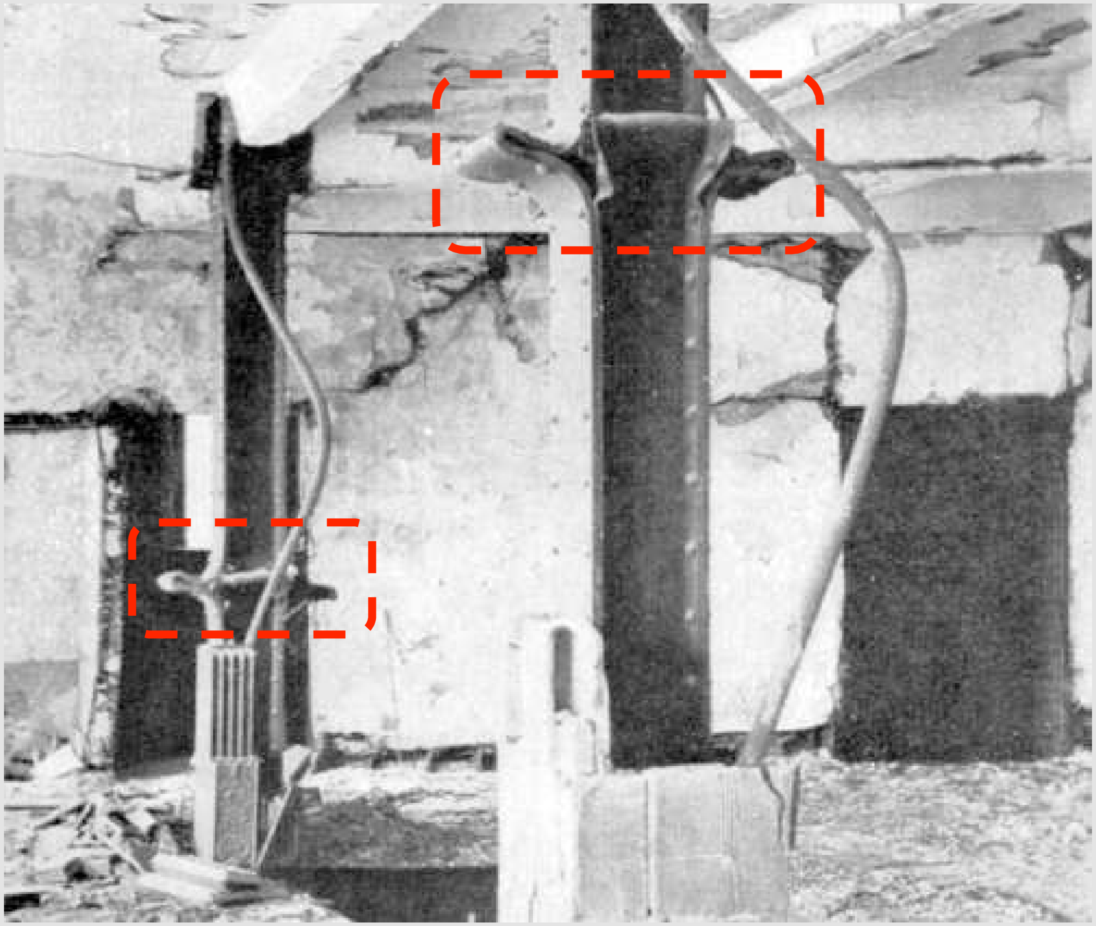
r = radius of gyration, in. (mm)

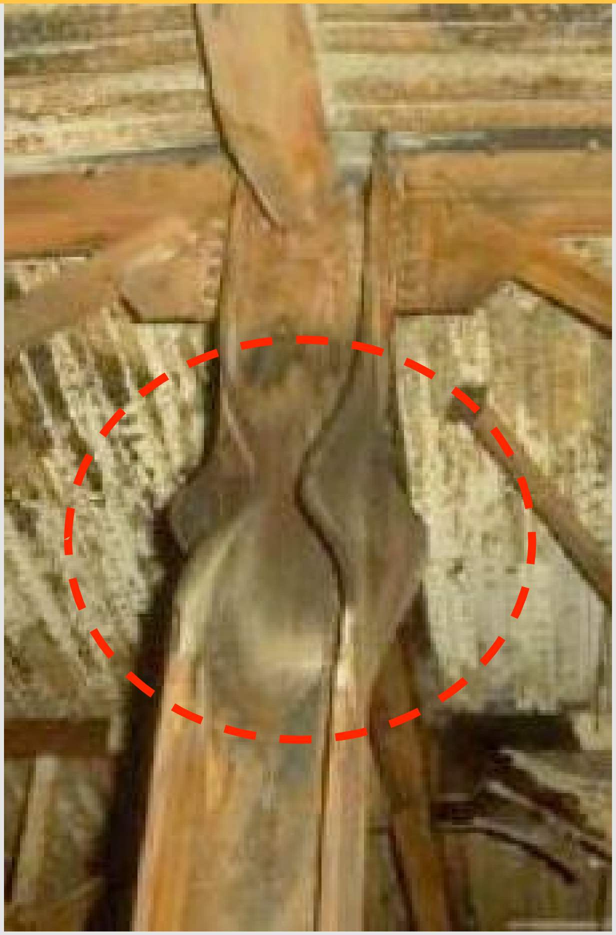
> **User Note:** For members designed on the basis of compression, the effective slenderness ratio KL/r preferably should not exceed 200.

- Why?
  - At high slenderness ratios, critical stress is very low (~ 5 ksi)

Sidebar: Buckling About r_x or r_y?

Local Buckling

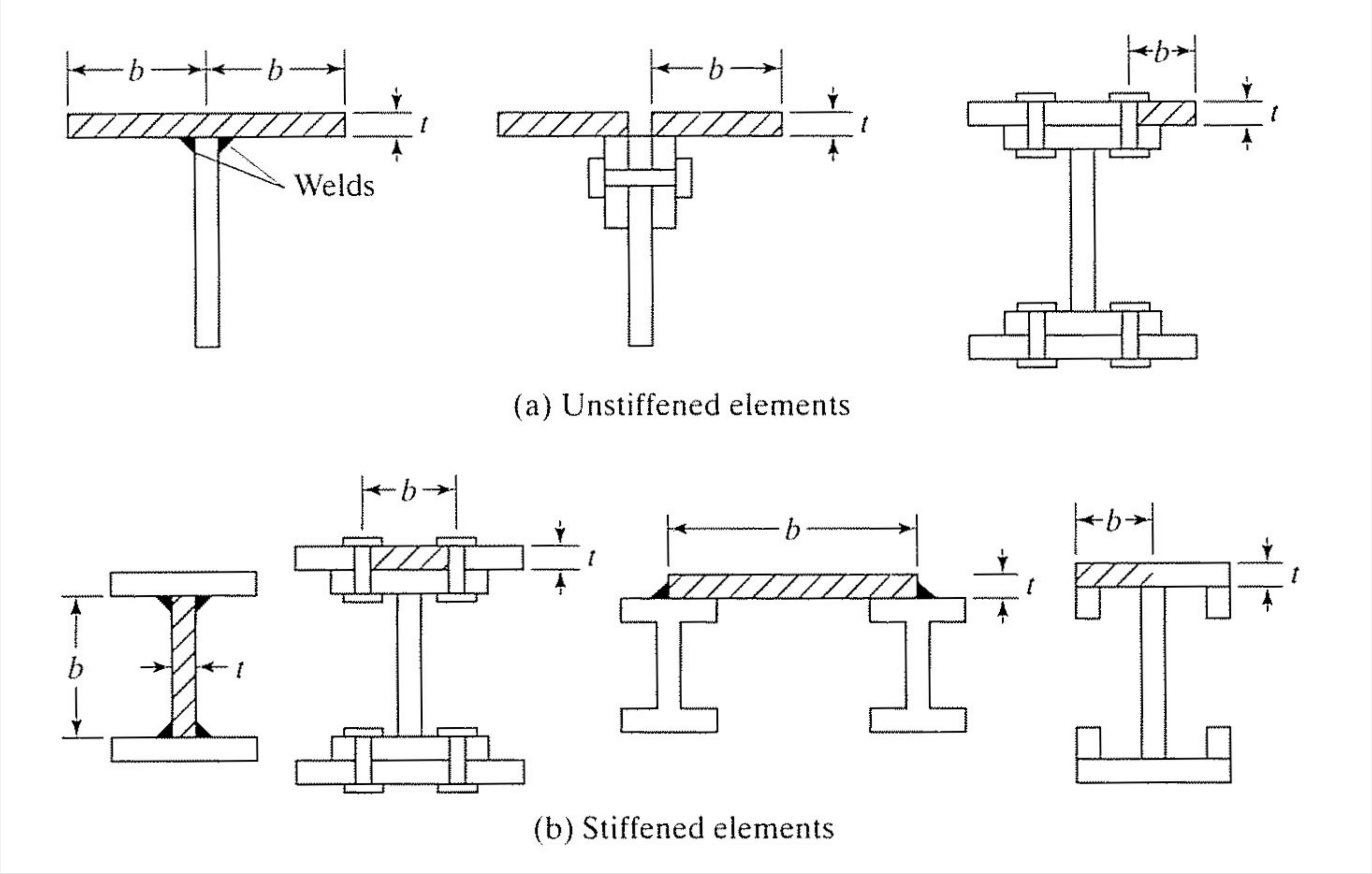




Local Buckling

- Stiffened Elements
  - A piece supported along two edges parallel to the direction of the compression force
- Unstiffened Elements
  - A piece with one free edge parallel to the direction of the compression force
- Key criterion is the width-thickness ratio (b/t ratio)

Stiffened & Unstiffened Elements



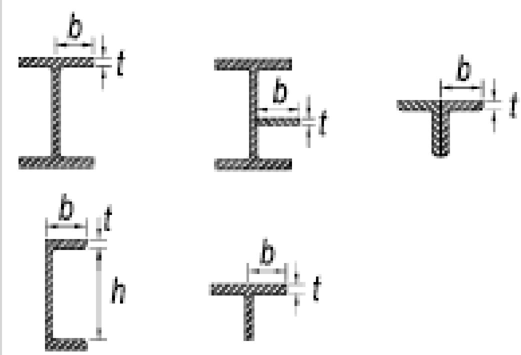
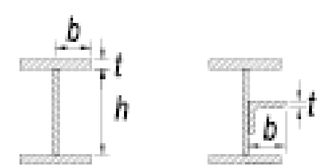
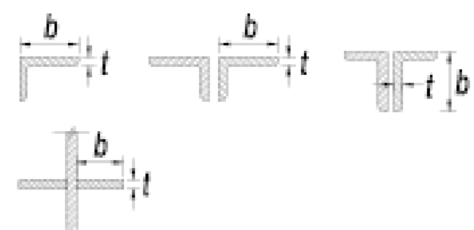
(a) Unstiffened elements

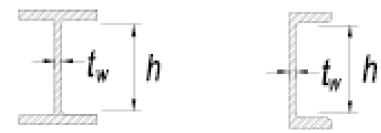
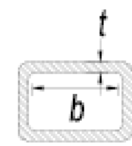
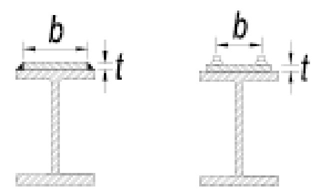
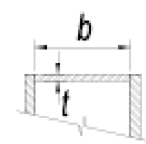
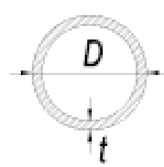
(b) Stiffened elements

Non-Slender Element vs. Slender-Element Sections

- Non-Slender Element Sections
  - Cross section is sufficiently "compact" so that global buckling will occur before local buckling of any cross-sectional elements
  - All elements of cross section must satisfy $b/t \leq \lambda_r$ from Spec Table B4.1a
- Slender-Element Section
  - Section with slender elements that may buckle locally before onset of global buckling
  - One that does not satisfy $b/t \leq \lambda_r$ requirement for one or more elements of the cross section
  - Must be checked per Spec Section E7 (complicated!)
- *Note: Terms "compact" and "non-compact" were used in the AISC 360-05 and previous standards. Terminology has been changed to clarify differing requirements for beams and columns.*

TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements
Members Subject to Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_cE}{F_y}}$ [a]	
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	

Stiffened Elements	**5**	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	
	6	Walls of rectangular HSS and boxes of uniform thickness	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$	

Nonslender Element vs. Slender-Element Sections

- Nearly all rolled sections are non-slender for compression, unless they are intended as beam shapes.
- Footnote in shape tables will alert you to slender-element sections.

W14×53	15.6	13.9	13 7/8	0.370	3/8	3/16	8.06	8	0.660	11/16	1.25	1 1/2	1	10 7/8	5 1/2
×48	14.1	13.8	13 3/4	0.340	5/16	3/16	8.03	8	0.595	5/8	1.19	1 7/16	1	↓	↓
×43[c]	12.6	13.7	13 5/8	0.305	5/16	3/16	8.00	8	0.530	1/2	1.12	1 3/8	1		
W14×38[c]	11.2	14.1	14 1/8	0.310	5/16	3/16	6.77	6 3/4	0.515	1/2	0.915	1 1/4	13/16	11 5/8	3 1/2[g]
×34[c]	10.0	14.0	14	0.285	5/16	3/16	6.75	6 3/4	0.455	7/16	0.855	1 3/16	3/4	↓	3 1/2
×30[c]	8.85	13.8	13 7/8	0.270	1/4	1/8	6.73	6 3/4	0.385	3/8	0.785	1 1/8	3/4		3 1/2

[c] Shape is slender for compression with $F_y = 50$ ksi.
[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.

Key Exclusions

- The provisions of Spec Section E3 consider the **flexural buckling** limit state.
- **Torsional buckling** and **flexural-torsional buckling** limit states also are possible, but we will not cover the details in the class.
- These provisions also assume that the compression element is not subject to local buckling prior to developing the strength noted. We must verify that the member is not **slender.**

Design Approach

- AISC SCM has a number of tables that facilitate the design:
  - Get to know PART 4
- Generally use Column Tables for design

Table for Critical Stress for Compression Members

Table 4-22

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

Table 4-22
Available Critical Stress for Compression Members

$F_y = 35$ ksi			$F_y = 36$ ksi			$F_y = 42$ ksi			$F_y = 46$ ksi			$F_y = 50$ ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD
1	21.0	31.5	1	21.6	32.4	1	25.1	37.8	1	27.5	41.4	1	29.9	45.0
2	21.0	31.5	2	21.6	32.4	2	25.1	37.8	2	27.5	41.4	2	29.9	45.0
3	20.9	31.5	3	21.5	32.4	3	25.1	37.8	3	27.5	41.4	3	29.9	45.0
4	20.9	31.5	4	21.5	32.4	4	25.1	37.8	4	27.5	41.4	4	29.9	44.9
5	20.9	31.5	5	21.5	32.4	5	25.1	37.7	5	27.5	41.3	5	29.9	44.9
6	20.9	31.4	6	21.5	32.3	6	25.1	37.7	6	27.5	41.3	6	29.9	44.9
7	20.9	31.4	7	21.5	32.3	7	25.1	37.7	7	27.5	41.3	7	29.8	44.8
8	20.9	31.4	8	21.5	32.3	8	25.1	37.7	8	27.4	41.2	8	29.8	44.8
9	20.9	31.4	9	21.5	32.3	9	25.0	37.6	9	27.4	41.2	9	29.8	44.7
10	20.9	31.3	10	21.4	32.2	10	25.0	37.6	10	27.4	41.1	10	29.7	44.7
11	20.8	31.3	11	21.4	32.2	11	25.0	37.5	11	27.3	41.1	11	29.7	44.6
12	20.8	31.3	12	21.4	32.2	12	24.9	37.5	12	27.3	41.0	12	29.6	44.5

Tables for Axial Capacity of Compression Members

Tables 4-1 through 4-20

Table 4-1
Available Strength in Axial Compression, kips
W-Shapes

W14

F_y = 50 ksi

Effective length, KL (ft), with respect to least radius of gyration, r_y

Shape	W14×											
lb/ft	730[h]		665[h]		605[h]		550[h]		500[h]		455[h]	
Design	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
radius of gyration, r_y	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
0	6440	9670	5870	8820	5330	8010	4850	7290	4400	6610	4010	6030
11	6070	9130	5530	8310	5010	7530	4550	6840	4120	6200	3750	5640
12	6010	9030	5470	8220	4950	7440	4500	6760	4070	6120	3710	5570
13	5940	8920	5400	8110	4890	7350	4440	6670	4020	6040	3660	5500
14	5860	8810	5330	8010	4820	7250	4380	6580	3960	5950	3600	5420
15	5780	8690	5250	7890	4750	7140	4310	6480	3900	5860	3550	5330
16	5690	8560	5170	7770	4680	7030	4240	6380	3840	5770	3490	5240
17	5610	8430	5090	7650	4600	6920	4170	6270	3770	5660	3420	5150
18	5510	8290	5000	7520	4520	6790	4100	6160	3700	5560	3360	5050

Properties

	730 ASD	730 LRFD	665 ASD	665 LRFD	605 ASD	605 LRFD	550 ASD	550 LRFD	500 ASD	500 LRFD	455 ASD	455 LRFD
P_{wo}, kips	2820	4230	2410	3620	2060	3090	1750	2630	1500	2240	1280	1920
P_{wi}, kips/in.	102	154	94.3	142	86.7	130	79.3	119	73.0	110	67.3	101
P_{wb}, kips	44000	66100	34400	51700	26600	40100	20500	30800	15900	23900	12500	18800
P_{fb}, kips	4510	6780	3820	5750	3240	4870	2730	4100	2290	3450	1930	2900

	730	665	605	550	500	455
L_p, ft	16.6	16.3	16.1	15.9	15.6	15.5
L_r, ft	275	253	232	213	196	179
A_g, in.^{2}	215	196	178	162	147	134
I_x, in.^{4}	14300	12400	10800	9430	8210	7190
I_y, in.^{4}	4720	4170	3680	3250	2880	2560
r_y, in.	4.69	4.62	4.55	4.49	4.43	4.38
r_x/r_y	1.74	1.73	1.71	1.70	1.69	1.67
$P_{ex}(KL)^2/10^4$, k-in.^{2}	409000	355000	309000	270000	235000	206000
$P_{ey}(KL)^2/10^4$, k-in.^{2}	135000	119000	105000	93000	82400	73300

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

[h] Flange thickness is greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.

Table 4-4
Available Strength in Axial Compression, kips
Square HSS

HSS16-HSS14

F_y = 46 ksi

Shape	HSS16×16×						HSS14×14×					
	1/2		3/8[c]		5/16[c]		5/8		1/2		3/8[c]	
t_{design}, in.	0.465		0.349		0.291		0.581		0.465		0.349	
lb/ft	103		78.5		65.9		110		89.7		68.3	
Design	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
0	780	1170	521	782	381	572	835	1250	678	1020	498	748
6	773	1160	518	779	379	570	825	1240	670	1010	494	743
7	770	1160	517	777	379	569	821	1230	667	1000	493	741
8	767	1150	516	776	378	568	817	1230	664	998	491	738
9	764	1150	515	774	377	567	813	1220	660	992	489	736
10	761	1140	513	772	376	566	808	1210	656	986	487	733
11	757	1140	512	769	375	564	802	1210	652	980	485	729
12	753	1130	510	767	374	563	796	1200	647	972	483	726
13	748	1120	508	764	373	561	790	1190	642	965	480	722
14	743	1120	506	761	372	559	783	1180	636	956	477	718
15	738	1110	504	758	371	557	775	1170	630	947	474	713
Properties												
A_g, in.^{2}	28.3		21.5		18.1		30.3		24.6		18.7	
$I_x = I_y$, in.^{4}	1130		873		739		897		743		577	
$r_x = r_y$, in.	6.31		6.37		6.39		5.44		5.49		5.55	

Effective length, KL (ft), with respect to least radius of gyration, r_y

dius of gyration, r_y

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

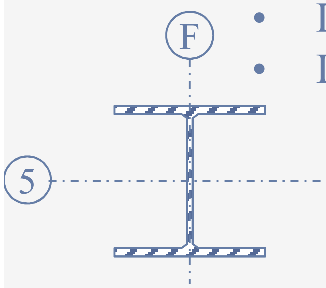
[c] Shape is slender for compression with $F_y = 46$ ksi.

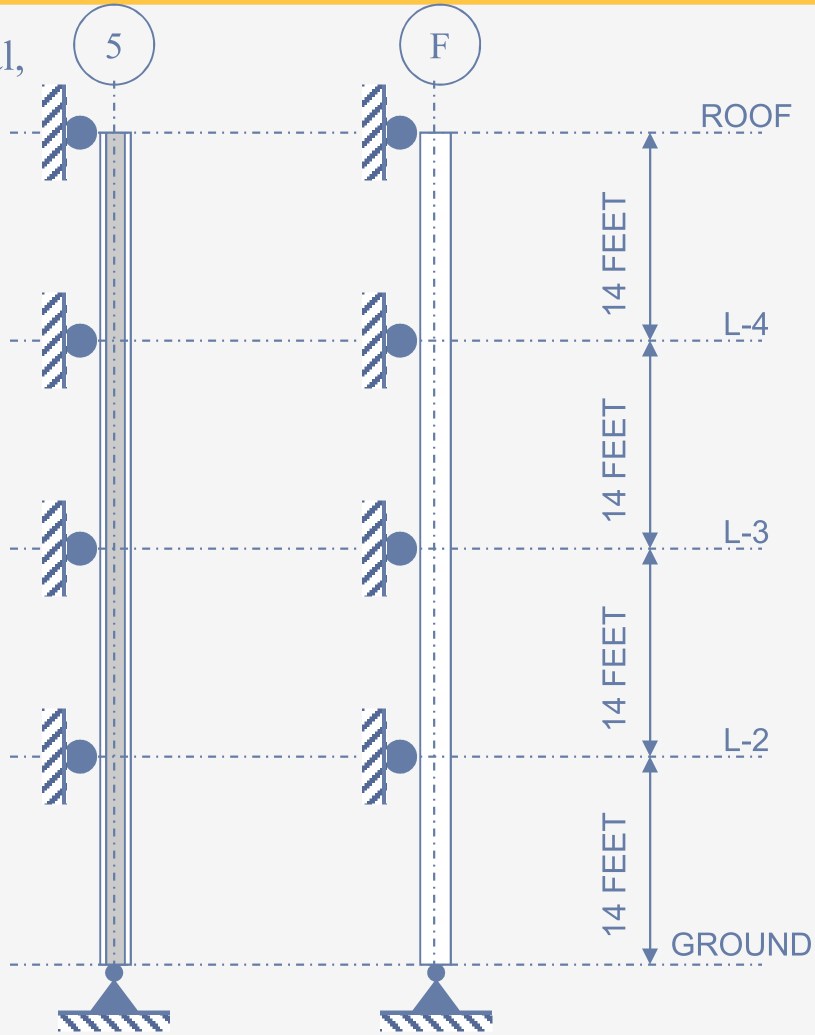
Questions?

Example Problem

Using only the design tables in the Steel Construction Manual, design the most efficient W10 wide flange steel column at Grid F/5 based on the conditions given below.

- The column is continuous from the ground level to the roof.
- The column supports a tributary area of 900 ft^2 at each floor.
- The loads on the column are as follows.
  - Level 2, 3 and 4
    - Dead Load = 120 psf
    - Live Load = 40 psf (non-reducible)
  - Roof
    - Dead Load = 100 psf
    - Live Load = 12 psf (non-reducible)





Example Problem

- Factored Load Tabulation (1.2 D + 1.6 L)

Level	Trib Area (ft^2)	w_D (psf)	w_L (psf)	w_U (psf)	P_u (kips)	ΣP_u (kips)
R	900	100	12	139	125	125
4	900	120	40	208	187	312
3	900	120	40	208	187	489
2	900	120	40	208	187	686

- Effective Length

  L = 14 ft, K = 1.0 (pin-pin)

Example Problem

Select W10x77

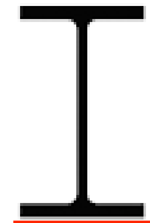
- Pn = 753 kips
- > Pu = 687 kips

Table 4-1 (continued)

Available Strength in Axial Compression, kips

W-Shapes

F_y = 50 ksi



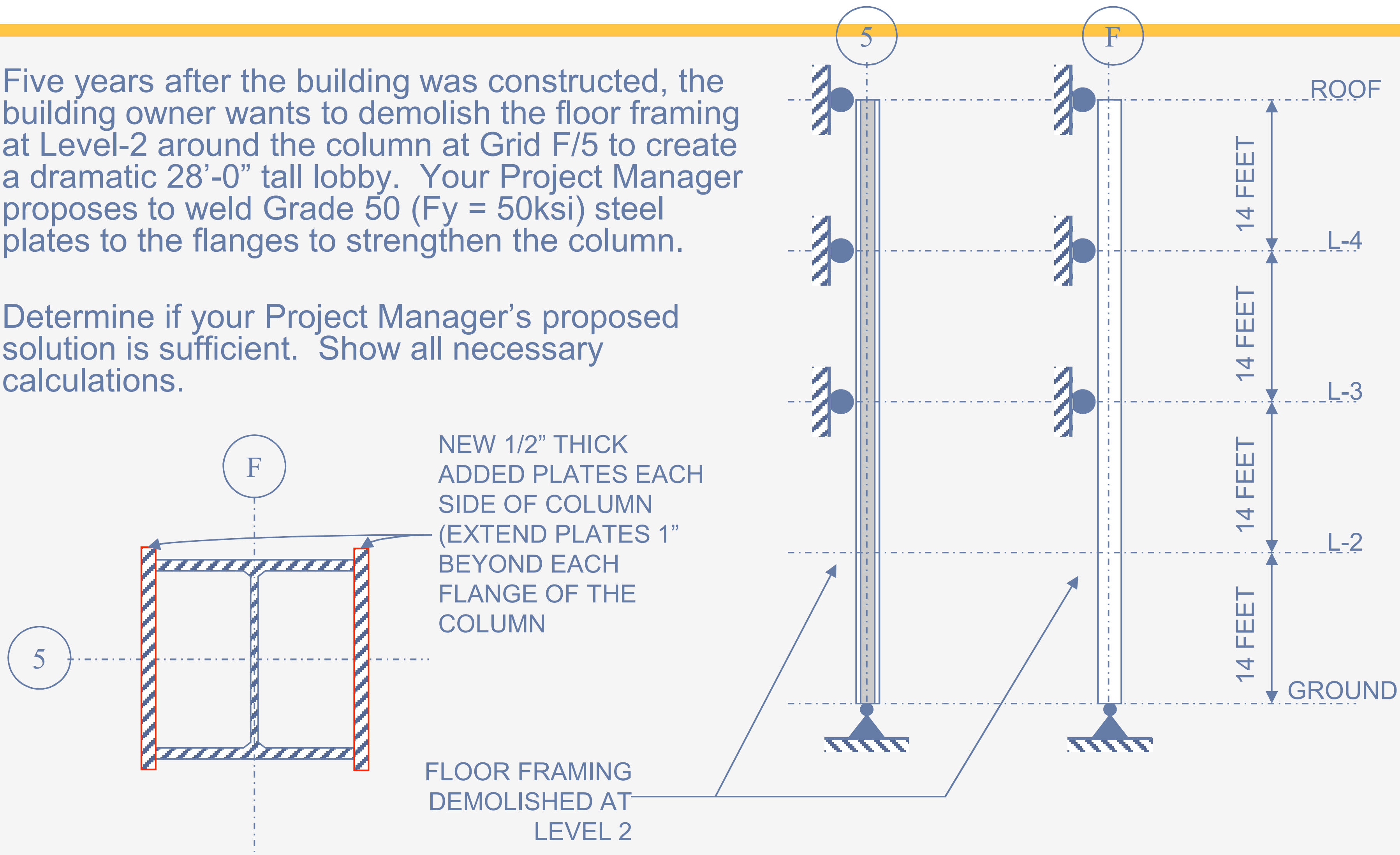
W10

Shape		W10×											
lb/ft		112		100		88		77		68		60	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
…least radius of gyration, r_y	0	985	1480	877	1320	778	1170	680	1020	596	895	530	796
	6	934	1400	831	1250	737	1110	643	966	563	846	500	752
	7	917	1380	815	1230	722	1090	630	946	552	829	490	737
	8	897	1350	797	1200	706	1060	615	925	539	810	479	719
	9	875	1310	777	1170	688	1030	599	900	525	789	466	700
	10	851	1280	755	1130	669	1000	582	874	509	765	452	679
	11	825	1240	732	1100	647	973	563	846	493	741	437	657
	12	798	1200	707	1060	625	940	543	816	475	714	421	633
	13	769	1160	681	1020	602	905	522	[illegible]	457	687	405	608
	14	739	1110	654	983	578	868	501	753	438	658	388	583
	15	708	1060	626	941	553	831	479	[illegible]	419	629	370	556

Example Problem

Five years after the building was constructed, the building owner wants to demolish the floor framing at Level-2 around the column at Grid F/5 to create a dramatic 28'-0" tall lobby. Your Project Manager proposes to weld Grade 50 (Fy = 50ksi) steel plates to the flanges to strengthen the column.

Determine if your Project Manager's proposed solution is sufficient. Show all necessary calculations.



Example Problem

- Factored Load Tabulation (1.2 D + 1.6 L)

Level	Trib Area (ft^2)	w_D (psf)	w_L (psf)	w_U (psf)	P_u (kips)	ΣP_u (kips)
R	900	100	12	139	125	125
4	900	120	40	208	187	312
3	900	120	40	208	187	489
~~2~~	~~900~~	~~120~~	~~40~~	~~208~~	~~187~~	~~686~~

No framing at 2nd floor

- Effective Length

  L = 28 ft, K = 1.0 (pin-pin)

Example Problem

Check W10 x77

P_n = 306 kips

< P_u = 489 kips

W10 x 77 must be retrofit

Shape		W10×							
lb/ft		112		100		88		77	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
e length, KL (ft), with respect to least radius of gyration, r_y	0	985	1480	877	1320	778	1170	680	1020
	6	934	1400	831	1250	737	1110	643	966
	7	917	1380	815	1230	722	1090	630	946
	8	897	1350	797	1200	706	1060	615	925
	9	875	1310	777	1170	688	1030	599	900
	10	851	1280	755	1130	669	1000	582	874
	11	825	1240	732	1100	647	973	563	846
	12	798	1200	707	1060	625	940	543	816
	13	769	1160	681	1020	602	905	522	785
	14	739	1110	654	983	578	868	501	753
	15	708	1060	626	941	553	831	479	720
	16	677	1020	598	898	527	792	456	686
	17	645	969	569	855	501	754	433	651
	18	613	921	540	811	475	714	410	617
	19	580	872	511	767	449	675	387	582
	20	548	824	482	724	423	636	365	548
	22	485	728	425	638	373	560	320	481
	24	423	636	370	556	324	487	277	417
	26	365	548	318	478	278	417	237	[illegible]
	28	315	473	274	412	239	360	204	307
	30	274	412	239	359	209	313	178	[illegible]

Example Problem

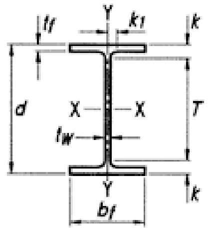
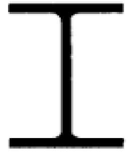


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k_{des}	Distance k_{det}	Distance k_1	Distance T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W12×58	17.0	12.2	12 1/4	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1 1/2	15/16	9 1/4	5 1/2
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1 3/8	15/16	9 1/4	5 1/2
W12×50	14.6	12.2	12 1/4	0.370	3/8	3/16	8.08	8 1/8	0.640	5/8	1.14	1 1/2	15/16	9 1/4	5 1/2
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1 3/8	15/16	↓	↓
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1 3/8	7/8	↓	↓
W12×35[c]	10.3	12.5	12 1/2	0.300	5/16	3/16	6.56	6 1/2	0.520	1/2	0.820	1 3/16	3/4	10 1/8	3 1/2
×30[c]	8.79	12.3	12 3/8	0.260	1/4	1/8	6.52	6 1/2	0.440	7/16	0.740	1 1/8	3/4	↓	↓
×26[c]	7.65	12.2	12 1/4	0.230	1/4	1/8	6.49	6 1/2	0.380	3/8	0.680	1 1/16	3/4	↓	↓
W12×22[c]	6.48	12.3	12 1/4	0.260	1/4	1/8	4.03	4	0.425	7/16	0.725	15/16	5/8	10 3/8	2 1/4[g]
×19[c]	5.57	12.2	12 1/8	0.235	1/4	1/8	4.01	4	0.350	3/8	0.650	7/8	9/16	↓	↓
×16[c]	4.71	12.0	12	0.220	1/4	1/8	3.99	4	0.265	1/4	0.565	13/16	9/16	↓	↓
×14[c,v]	4.16	11.9	11 7/8	0.200	3/16	1/8	3.97	4	0.225	1/4	0.525	3/4	9/16	↓	↓
W10×112	32.9	11.4	11 3/8	0.755	3/4	3/8	10.4	10 3/8	1.25	1 1/4	1.75	1 15/16	1	7 1/2	5 1/2
×100	29.3	11.1	11 1/8	0.680	11/16	3/8	10.3	10 3/8	1.12	1 1/8	1.62	1 13/16	1	↓	↓
×88	26.0	10.8	10 7/8	0.605	5/8	5/16	10.3	10 1/4	0.990	1	1.49	1 11/16	15/16	↓	↓
×77	22.7	10.6	10 5/8	0.530	1/2	1/4	10.2	10 1/4	0.870	7/8	1.37	1 9/16	7/8	↓	↓
×68	19.9	10.4	10 3/8	0.470	1/2	1/4	10.1	10 1/8	0.770	3/4	1.27	1 7/16	7/8	↓	↓
×60	17.7	10.2	10 1/4	0.420	7/16	1/4	10.1	10 1/8	0.680	11/16	1.18	1 3/8	13/16	↓	↓
×54	15.8	10.1	10 1/8	0.370	3/8	3/16	10.0	10	0.615	5/8	1.12	1 5/16	13/16	↓	↓
×49	14.4	10.0	10	0.340	5/16	3/16	10.0	10	0.560	9/16	1.06	1 1/4	13/16	↓	↓

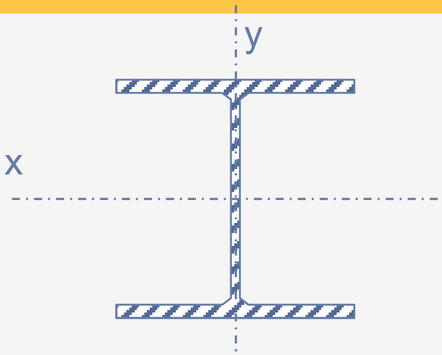
Table 1-1 (continued)
W-Shapes
Properties



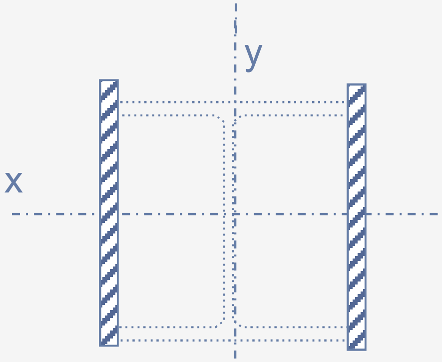
W12-W10

Nominal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
58	7.82	27.0	475	78.0	5.28	86.4	107	21.4	2.51	32.5	2.81	11.6	2.10	3570
53	8.69	28.1	425	70.6	5.23	77.9	95.8	19.2	2.48	29.1	2.79	11.5	1.58	3160
50	6.31	26.8	391	64.2	5.18	71.9	56.3	13.9	1.96	21.3	2.25	11.6	1.71	1880
45	7.00	29.6	348	57.7	5.15	64.2	50.0	12.4	1.95	19.0	2.23	11.5	1.26	1650
40	7.77	33.6	307	51.5	5.13	57.0	44.1	11.0	1.94	16.8	2.21	11.4	0.906	1440
35	6.31	36.2	285	45.6	5.25	51.2	24.5	7.47	1.54	11.5	1.79	12.0	0.741	879
30	7.41	41.8	238	38.6	5.21	43.1	20.3	6.24	1.52	9.56	1.77	11.9	0.457	720
26	8.54	47.2	204	33.4	5.17	37.2	17.3	5.34	1.51	8.17	1.75	11.8	0.300	607
22	4.74	41.8	156	25.4	4.91	29.3	4.66	2.31	0.848	3.66	1.04	11.9	0.293	164
19	5.72	46.2	130	21.3	4.82	24.7	3.76	1.88	0.822	2.98	1.02	11.9	0.180	131
16	7.53	49.4	103	17.1	4.67	20.1	2.82	1.41	0.773	2.26	0.983	11.7	0.103	96.9
14	8.82	54.3	88.6	14.9	4.62	17.4	2.36	1.19	0.753	1.90	0.961	11.7	0.0704	80.4
112	4.17	10.4	716	126	4.66	147	236	45.3	2.68	69.2	3.08	10.2	15.1	6020
100	4.62	11.6	623	112	4.60	130	207	40.0	2.65	61.0	3.04	10.0	10.9	5150
88	5.18	13.0	534	98.5	4.54	113	179	34.8	2.63	53.1	2.99	9.81	7.53	4330
77	5.86	14.8	455	85.9	4.49	97.6	154	30.1	2.60	45.9	2.95	9.73	5.11	3630
68	6.58	16.7	394	75.7	4.44	85.3	134	26.4	2.59	40.1	2.92	9.63	3.56	3100
60	7.41	18.7	341	66.7	4.39	74.6	116	23.0	2.57	35.0	2.88	9.52	2.48	2640
54	8.15	21.2	303	60.0	4.37	66.6	103	20.6	2.56	31.3	2.85	9.49	1.82	2320
49	8.93	23.1	272	54.6	4.35	60.4	93.4	18.7	2.54	28.3	2.84	9.44	1.39	2070

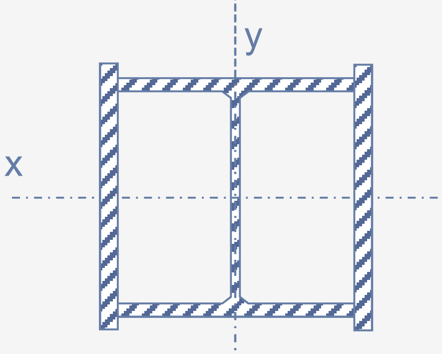
Example Problem



- W10x77
  - $A = 22.7\ in^2$
  - $d = 10.6\ in$
  - $b_f = 10.2\ in$
  - $I_x = 455\ in^4$
  - $I_y = 154\ in^4$



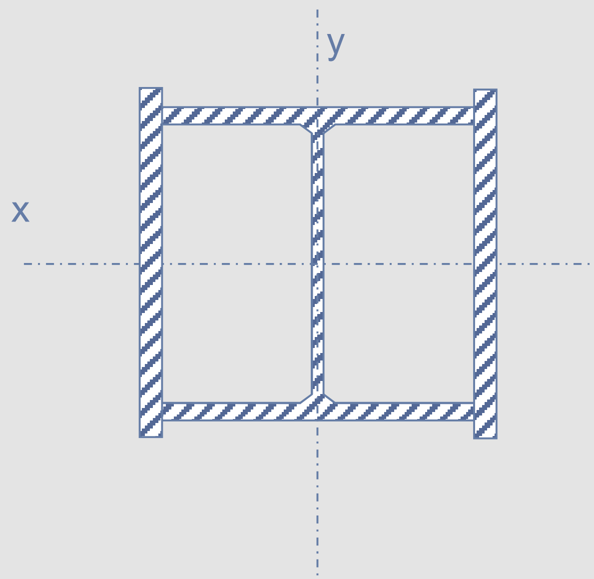
- Plates (about N.A. of W10x77)
  - $d = 10.6" + 2\ (1") = 12.6"$
  - $A = (2\ pl)\ (12.6")\ (1/2") = 12.6\ in^2$
  - $I_x = (2\ pl)\ (1/2")\ (12.6")^3 / 12 = 167\ in^4$
  - $I_y = (2\ pl)\ (1/2")\ (12.6")\ (10.2 / 2 + 0.5 / 2)^2 = 361\ in^4$



- Combined
  - $A = 22.7 + 12.6 = 35.3\ in^2$
  - $I_x = 455 + 167 = 622\ in^4$
  - $I_y = 154 + 361 = 515\ in^4$

  $r_{min} = \frac{I_{min}}{A}$ (about y)

Example Problem



- Confirm new cross section is nonslender for local buckling:

- W14x77 was not indicated as a slender-element section in the shape tables.
  - Therefore, no need to check any elements of that original section

- Check new retrofit plates:

$$b/t = 10.6/0.5 = 21.2$$

$$\lambda_r = 1.49\sqrt{E/F_y}$$

Example Problem

- Factored Load Tabulation (1.2 D + 1.6 L)

Level	Trib Area (ft^2)	w_D (psf)	w_L (psf)	w_U (psf)	P_u (kips)	ΣP_u (kips)
R	900	100	12	139	125	125
4	900	120	40	208	187	312
3	900	120	40	208	187	489
~~2~~	~~900~~	~~120~~	~~40~~	~~208~~	~~187~~	~~686~~

Floor demolished so no load

- Effective Length
  L = 28 ft, K = 1.0 (pin-pin)
- KL/r = (1.0) (28' x 12"/ft) / 3.82" = 88
  (for combined section)

Example Problem

KL/r = 88

$\phi_c F_{cr}$ = 25.5 ksi

$\phi P_n = \phi_c F_{cr} A$

= 25.5 x 35.3

= 900 kips

P_u = 489 kips

RETROFIT ACCEPTABLE

Table 4-22 (continued)

Available Critical Stress for Compression Members

F_y = 35 ksi			F_y = 36 ksi			F_y = 42 ksi			F_y = 46 ksi			F_y = 50 ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD
81	15.0	22.5	81	15.3	22.9	81	16.8	25.3	81	17.7	26.6	81	18.5	27.9
82	14.9	22.3	82	15.1	22.7	82	16.6	25.0	82	17.5	26.3	82	18.3	27.5
83	14.7	22.1	83	15.0	22.5	83	16.5	24.8	83	17.3	26.0	83	18.1	27.2
84	14.6	22.0	84	14.9	22.3	84	16.3	24.5	84	17.1	25.8	84	17.9	26.9
85	14.5	21.8	85	14.7	22.1	85	16.1	24.3	85	16.9	25.5	85	17.7	26.5
86	14.4	21.6	86	14.6	22.0	86	16.0	24.0	86	16.7	25.2	86	17.4	26.2
87	14.2	21.4	87	14.5	21.8	87	15.8	23.7	87	16.6	24.9	87	17.2	25.9
88	14.1	21.2	88	14.3	21.6	88	15.6	23.5	88	16.4	24.6	88	17.0	25.5
89	14.0	21.0	89	14.2	21.4	89	15.5	23.2	89	16.2	24.3	89	16.8	25.2
90	13.8	20.8	90	14.1	21.2	90	15.3	23.0	90	16.0	24.0	90	16.6	24.9
91	13.7	20.6	91	13.9	21.0	91	15.1	22.7	91	15.8	23.7	91	16.3	24.6
92	13.6	20.4	92	13.8	20.8	92	15.0	22.5	92	15.6	23.4	92	16.1	24.2
93	13.5	20.2	93	13.7	20.5	93	14.8	22.2	93	15.4	23.1	93	15.9	23.9